NATIONAL ENERGY TECHNOLOGY LABORATORY

Advanced Sensors and Controls - Techno-Economic Analysis for Existing Coal Generating Units

Katrina Krulla, Jeff Withum, Paul Myles, Peter Kabatec

March 8, 2013

DOE/NETL-342/03082013

U.S. DEPARTMENT OF ENERGY

OFFICE OF FOSSIL ENERGY

Table of Contents

Executive Summary

The National Energy Technology Laboratory (NETL) has a program to develop advanced sensing and control technologies that can be utilized in the coal power generating fleet. The portfolio of technologies being developed is comprehensive, ranging from wireless data transmitters, to advanced computational methods, to sapphire fiber optics. Since many of these technologies are in the early research and development (R&D) phase, cost and performance data is uncertain.

This study collected data from previous coal-fired power plant sensor and control projects and used this data to establish cost and performance ranges to determine the economic opportunity. Unit-level economic analyses were performed on coal-fired power plants in the U.S. by calculating the net present value (NPV) of cash flows that occur after the installation of new advanced sensor and control technologies in 2020. The results indicate that all 863 coal-fired units in the U.S. would meet a 24-month payback criterion assuming that availability and heat rate would improve consistent with prior senor and control projects.

An evaluation of advanced sensor and control technologies was also performed using the National Energy Modeling System (NEMS). While the NPV analysis is static, the NEMS uses an iterative approach to project the U.S. energy economy through 2035. The NEMS analysis showed that 133GW to 255GW of the coal-fired power plant fleet could economically retrofit with a return on investment to the U.S. taxpayer in the range of 5:1 to 15:1. The NEMS analysis also showed a reduction in NOx of three to five percent per year plus CO_2 reductions of 20 million metric tons per year by 2035.

1 Introduction

The performance of coal-fired power plants is limited by the lack of sensors and controls capable of withstanding high temperature and pressure conditions. Harsh environments are inherent to new systems that aim to achieve high efficiency with low emissions. In addition, these systems are complex, with operational constraints and system integration challenges that push the limits of traditional process controls. NETL's Crosscutting Research Program is developing sensing and control technologies and methods to achieve seamless, integrated, automated, optimized, and intelligent power systems.

The objective of this study is to estimate the economic opportunity and potential environmental benefits of installing advanced sensors and controls technologies at existing coal-fired power plants. This was accomplished by identifying quantifiable metrics and developing a defensible approach to isolating and estimating the impacts of sensors and controls technologies in electricity generation power plants.

2 Methodology

A net present value (NPV) model was developed for this study to determine which coal-fired units could economically retrofit with advanced sensors and controls. The NPV model assumes that a unit must meet a two year payback hurdle before the project is deemed economic. Unit level historical generation data was obtained directly from Ventyx's Velocity Suite[1]. This data was then combined with estimates for advanced sensor and control retrofit cost and performance to examine various retrofit scenarios. Cost and performance ranges for advanced sensor and control retrofit projects were obtained from publically available publications and discussions with engineers.

The results of the NPV model were then used to derive inputs for NEMS [2] simulations to estimate economic and environment benefits of the advanced sensors and controls program. The NEMS is a fully integrated, energy-economy modeling system that balances supply and demand of U.S. through 2030. NEMS is used by Energy Information Administration to project the energy, economic, environmental, and security impacts on the United States of alternative energy policies and different assumptions about energy markets. This study modified the 2011 NEMS code to allow for advanced sensor and control retrofits.

3 Cost and Performance Inputs

NETL identified several key drivers for the decision to retrofit a coal fired generating unit with advanced sensors and controls:

Efficiency improvement

Availability increase

[1] Ventyx, Velocity Suite, Data Version 2011-05, https://velocitysuite.globalenergy.com. Units scheduled to retire before 2020 and units smaller than 50 MW capacity were not included in this study. This left 863 coal-fired units in the data base

[2] EIA, National Energy Modeling System, 2011 version, http://www.eia.gov/forecasts/aeo/appendixe.cfm#nems

NOx reduction

Capital cost of the project

Additional operating cost

Labor savings

After conducting literature searches and engaging in discussions with industry stakeholders, ranges for the above inputs were established.

3.1 Efficiency

NETL previously examined the opportunity for efficiency improvements in the existing coal fired power units by comparing the characteristics of the most efficient units against the rest of the fleet. Figure 1 shows that some of the most efficient units are able to achieve high efficiency rates despite being sub-critical, under 200MW, burning sub-bituminous coal, etc.

Figure 1: Characteristics of the most efficient coal generating units and the rest of the fleet[3]

	2008 Top 10%		2008 Rest of Fleet	
	Average	Range	Average	Range
Generation Weighted Efficiency	37.6%	36.3% - 43.7%	32.0%	19.5% - 36.2%
Capacity (MW)	580	114 - 1426	329	27 - 1300
% of units that are Super Critical	55%	-	10%	-
Steam Pressure (psig)	2935	1800 - 3500	2088	600 - 5000
Age (yrs)	40	1 - 54	42	1 - 69
Load Factor*	83%	67% - 99%	75%	24% - 105%
% of units burning Bituminous Coal	66%	-	56%	-
% of units with SO2 Controls	36%	-	35%	-

To further understand existing coal unit efficiency, NETL examined the ten year historical efficiency of each existing coal unit and ranked them in groups based on their efficiency. It is worth noting that the least efficient plants, decile 1, were on average, 2 percentage points more efficient at one time during their ten year history. This trend holds up for each decile, suggesting

[3] DiPietro, Joseph & Katrina, Krulla. Improving the Efficiency of Coal-Fired Power Plants for Near Term Greenhouse Gas Emissions Reductions http://www.netl.doe.gov/energy-analyses/pubs/ImpCFPPGHGRdctns_0410.pdf, page 2

that there is significant opportunity for advanced sensors and controls to impact existing coal unit efficiency.

Figure 2: Best year generation-weighted efficiency[4]

Decile	2008 Efficiency	1998 - 2008 Best Year Efficiency
1	27.6%	29.9%
2	29.9%	31.7%
3	30.8%	32.5%
4	31.6%	33.3%
5	32.2%	34.1%
6	32.9%	35.0%
7	33.8%	35.8%
8	34.7%	36.9%
9	35.7%	37.7%
10	37.6%	39.7%
Average	**32.5%**	**34.5%**

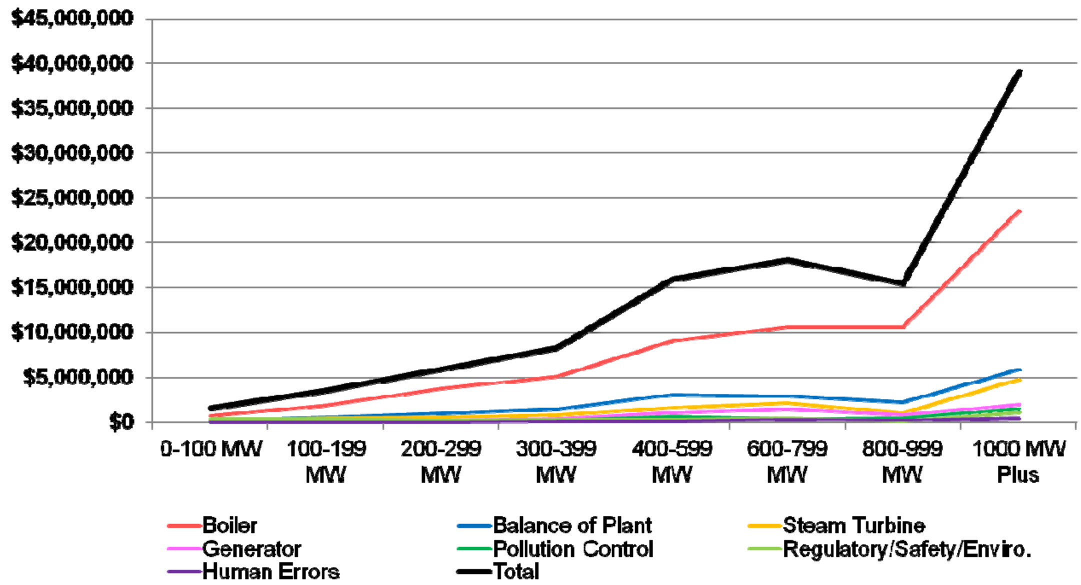
3.2 Availability

NETL engaged industry stakeholders in a coal-fired power plant efficiency workshop in 2009[5] where discussions often focused on the importance of availability over efficiency. To quantify the opportunity for advanced sensors and controls to impact availability, NETL examined the NERC GADS database to determine the cause of forced outages and the economic impact of each outage. Figure 3 shows that the annual economic impact from forced outages ranges from $8 million for a 300MW plant to almost $40 million for a 1000MW plant.

[4] DiPietro, Joseph & Katrina, Krulla. Improving the Efficiency of Coal-Fired Power Plants for Near Term Greenhouse Gas Emissions Reductions http://www.netl.doe.gov/energy-analyses/pubs/ImpCFPPGHGRdctns_0410.pdf, page 5

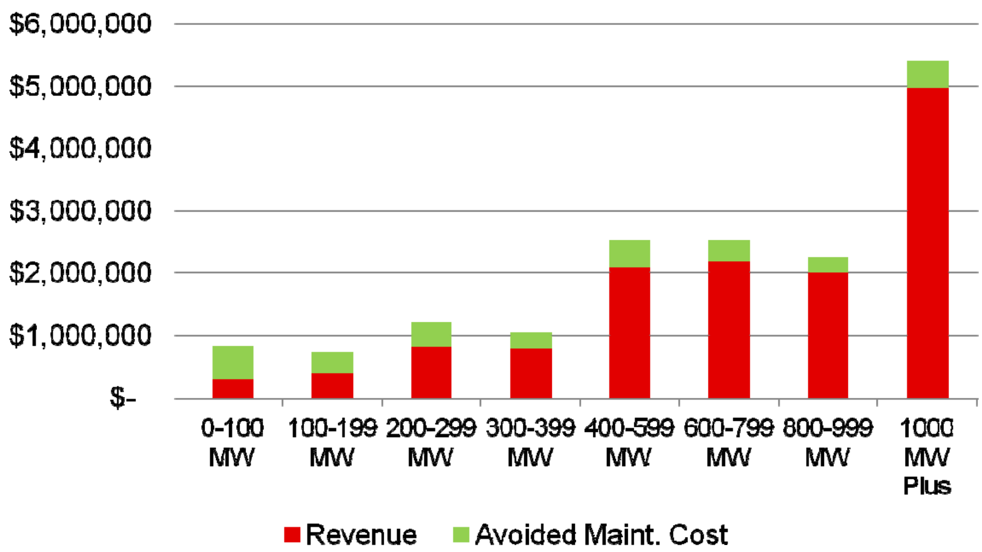
[5] Eisenhower, Jack & Richard Scheer. Opportunities to Improve the Efficiency of Existing Coal□fired Power Plants, Workshop Report. http://www.netl.doe.gov/energy-analyses/pubs/NETL%20Power%20Plant%20Efficiency%20Workshop%20Report%20Final.pdf

Figure 3: 2005-2009 Average annual plant revenue loss due to equipment forced outages and derates (2011 $)[6]



To further quantify the opportunity for advanced sensors and controls to impact forced outages, NETL assumed a ten percent reduction in forced outages due to equipment failure and a ninety percent reduction for human errors. Figure 4 shows the economic impact if advanced sensors and controls achieved such reductions.

Figure 4: Potential revenue increase and avoided maintenance costs - 10% decrease in forced and unplanned maintenance outages[7]



[6] Myles, Paul. Potential Impact of Improved Sensors, Controls on Coal-Fired Power Plant Forced Outages.
[7] Table Developed by Myles, Paul, based on Potential Impact of Improved Sensors, Controls on Coal-Fired Power Plant Forced Outages.

3.3 Input Ranges

NETL examined previous sensor and control retrofit projects and spoke with industry experts to form ranges for cost and performance inputs. Figure 5 summarizes the ranges that were recommended by Worley Parsons for use in the NPV model.

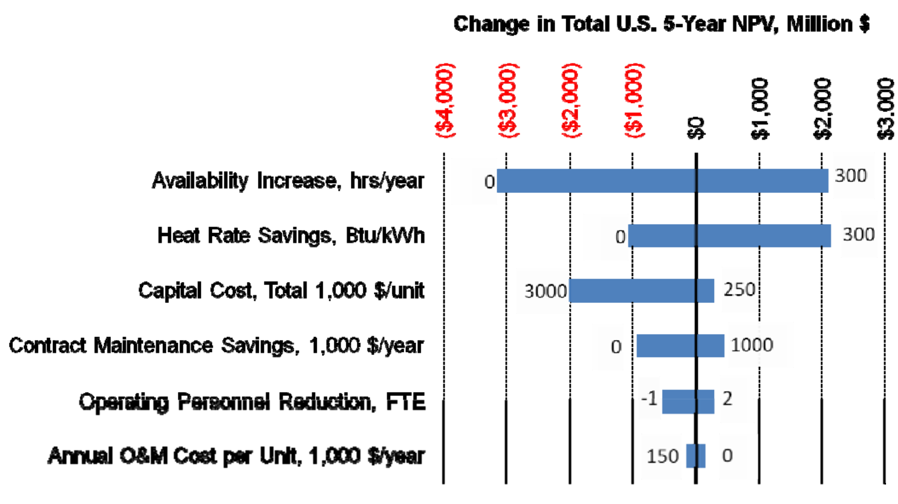
Figure 5: Cost and performance ranges of previous sensors and controls projects[8]

MWs	Capital Cost (Thousand $)	O&M Cost (Thousand $/yr)	Reduction in Operator Cost (Thousand $/yr/unit)	Reduction in HR (Btu/KWh)	Nox Reduction (%)	Availability Improvements: Increased Operation Hours (Hr/Yr)	Availability Improvements: Net Generation Increase (MWh)	Availability Improvements: Contract Maint. Savings (Thousand $/Yr)
0-99	$500 - $600	$50 - $60	$120	175 - 225	5 - 8	75	4,500	$450
100-199	$500 - $600	$50 - $60	$120	175 - 225	5 - 8	79	10, 700	$470
200-299	$600 - $700	$60 - $70	$120	125 - 175	5 - 8	77	17,500	$460
300-399	$600 - $700	$60 - $70	$120	125 - 175	5 - 8	78	25,500	$465
400-599	$800 - $900	$70 - $80	$120	75 - 125	5 - 8	100	52,000	$600
600-799	$800 - $900	$70 - $80	$120	75 - 125	5 - 8	85	56,500	$510
800-999	$900- $1,000	$80 - $90	$120	25 - 75	5 - 8	55	46,000	$325
1000+	$900 - $1,000	$80 - $90	$120	25 - 75	5 - 8	100	125, 000	$600

3.4 Sensitivities

When examining the results of an economic model, it is important to explore the sensitivity of the results to the input assumptions. Sensitivities to inputs variables were tested doing a one-at-a-time variation of the NPV model inputs. Figure 6 lists the key inputs in order of significance.

Figure 6: NPV model sensitivities to inputs



---

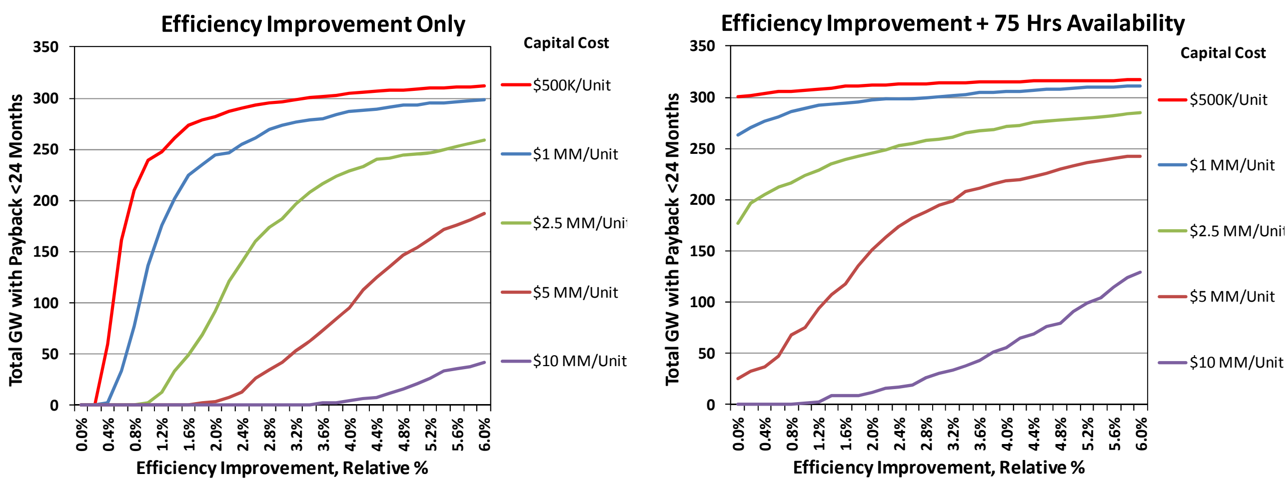
8 Table developed by Myles, Paul and Peter, Kabatec. Supporting Documents: Potential Impact of Improved Sensors, Controls on Coal-Fired Power Plant Forced Outages & Impact of Existing Sensors and Controls on Coal-Fired Power Plant Performance. Reduction in operator cost - one operator per unit @ $35/hr , 1.25-1.3 multipliers for benefits. Availability improvements - $5952/outage hr maintenance savings.

4 NPV Model Results

The sensitivity analysis showed that availability, efficiency, and capital cost were the most important variables in the advanced sensor and control retrofit decision. Figure 7 reports cost and efficiency ranges where it is economic for existing coal units to retrofit assuming a 24 month payback period. The graph on the left assumes that the existing fleet will only benefit from efficiency improvements and reports the total capacity of the US coal fleet that can economically retrofit. The graph on the right uses the same assumptions but assumes that each unit achieves an extra 75 hours of availability during the year due to reduced forced outages. To give an example of the importance of availability:

- A $5 million retrofit project that impacted efficiency only, would be economic for 100GW of the US coal fleet if it achieved a 4% efficiency improvement.
- The same $5 million retrofit project could be economic for 100GW of the fleet with 75 additional hours of availability and a 1.3% increase in efficiency.

Figure 7: Impacts of Efficiency, Availability and Capital Cost



4.1 Base Case Results

A base case scenario was constructed in the NPV model based on the average for each range in Figure 5. This scenario was then used to estimate potential market penetration, economic return, and environmental benefits.

Figure 8: Base case inputs

Unit Size	Capital Cost ($)	Fixed/Variable O&M Cost ($/yr)	Reduction in Personnel (No. of People)	Reduction in Operator Cost# ($/yr/unit)	Heat Rate Improvement (Btu/KWh)	Potential NOx Reduction Emissions (%)	Availability Improvements*: Additional Unit Operation Hours (Hr/Yr)	Availability Improvements*: Additional Unit Avg. Net Generation Increase (MWh)	Availability Improvements*: Additional Unit Contract Maintenance Savings ($/Yr)
50-99 MW (72 Avg)	$550,000	$55,000	1.0	$118,300	200	6.5	91.0	6,552	$ 541,632
100-199 MW (147 Avg)	$550,000	$55,000	1.0	$118,300	200	6.5	54.0	7,938	$ 321,408
200-299 MW (241 Avg)	$650,000	$65,000	1.0	$118,300	150	6.5	65.0	15,665	$ 386,880
300-399 MW (350 Avg)	$650,000	$65,000	1.0	$118,300	150	6.5	44.0	15,400	$ 261,888
400-599 MW (515 Avg)	$850,000	$75,000	1.0	$118,300	100	6.5	74.0	38,110	$ 440,448
600-799 MW (673 Avg)	$850,000	$75,000	1.0	$118,300	100	6.5	60.0	40,380	$ 357,120
800-999 MW (868 Avg)	$950,000	$85,000	1.0	$118,300	50	6.5	43.0	37,324	$ 255,936
> 1,000 MW (1261 Avg)	$950,000	$85,000	1.0	$118,300	50	6.5	73.0	92,053	$ 434,496

#Assumes decrease of 1 operator position per unit with operator pay @ $35/hr with 1.3 and 1.25 multipliers for benefits per WorleyParsons' cost estimation department.

* Assumes $5,952/outage hour maintenance savings based on Worley Parsons experience.

Using the default inputs and assuming a 24 month payback period, the NPV model projects that all 863 coal-fired units would meet the 24-month payback criterion. The nationwide total NPV would be greater than $4.2 billion after 5 years and nearly $8 billion after 10 years. The average internal rate of return nationwide would be 177 percent. Thus, there would be a substantial benefit from the successful development and deployment of advanced sensors and controls. The results are given in Figure 9.

Figure 9: NPV base case – Economic results

Unit Size	No. of Units	Total GW	No. of Units with Payback <24 mo.	Total GW with Payback <24 mo.	Average Payback Time (months)	Average IRR (%)	Average 5-year NPV ($MM)	Average 10-year NPV ($MM)	Average 20-year NPV ($MM)	Total U.S. 5-year NPV ($MM)	Total U.S. 10-year NPV ($MM)	Total U.S. 20-year NPV ($MM)
50-99 MW (72 Avg)	143	10.4	143	10.4	10.6	122%	2.3	4.4	7.2	329	624	1,029
100-199 MW (147 Avg)	183	26.9	183	26.9	10.3	128%	2.4	4.6	7.7	447	848	1,406
200-299 MW (241 Avg)	126	30.3	126	30.3	8.2	161%	3.8	7.1	11.9	478	898	1,496
300-399 MW (350 Avg)	68	23.8	68	23.8	7.7	169%	4.0	7.5	12.4	273	511	844
400-599 MW (515 Avg)	145	74.7	145	74.7	5.8	227%	7.4	13.8	23.2	1,076	2,008	3,365
600-799 MW (673 Avg)	125	84.1	125	84.1	5.2	250%	7.4	15.3	25.4	1,031	1,910	3,179
800-999 MW (868 Avg)	61	52.9	61	52.9	6.9	189%	6.7	12.7	21.4	411	774	1,308
> 1,000 MW (1261 Avg)	12	15.1	12	15.1	3.2	403%	15.5	28.5	48.0	186	342	576
U.S. Average:					8.0	177%	4.9	9.2	15.3			
Total U.S.:	863	318.3	863	318.3						4,231	7,913	13,204

5 NEMS Model Results

The NEMS model was selected as an additional tool to assess potential market opportunity and benefits of the NETL advanced sensors and controls program. While the NPV model uses several variables to capture the unit level economic feasibility to retrofit at a single time point, the NEMS provides an integrated projection through 2035 with a detailed representation of the entire energy economy. To utilize the NEMS to assess advanced sensors and controls, the 2011 model[9] and default inputs were modified to allow existing coal units to retrofit[10] based on the assumptions developed in Figure 8. Three NEMS cases were then produced:

- Reference case – uses default 2011 assumptions
- No New Source Review (NSR) case – units can install advanced sensors and controls without upgrading emission controls
- NSR case – units lacking SO_2, NOx, or Hg controls must first install all controls before adding advanced sensors and controls

5.1 NEMS Results

The results of the three NEMS cases are summarized in Figure 11.

Figure 11: Year 2035 NEMS Case Results

	Refurbish Capacity (GW)	Coal Generation (BkWh)	Ave. US COE (2009¢/kWh)	Total Electric Sales (BkWh)	US Electric Bill (Billions 2009$)
Reference	0	2197	9.2	4474	412
No NSR	255	2225	9.1	4491	410
With NSR	133	2204	9.2	4477	411

The total capacity of the US coal fleet that retrofits with advanced sensors and controls by 2035 in the No NSR case is 255GW, slightly less than the 283GW in the NPV model[11]. The NSR case still shows significant economic opportunity for advanced sensors and controls assuming units are required to first upgrade emission control equipment. It is worth noting that in both cases, NSR and no NSR, there is feedback to the overall price of electricity resulting in lower average consumer cost of electricity. This result can then be used to compute the economic return on investment of NETL research in advanced sensors and controls technology. Assuming that the program is funded at current levels, the internal rate of return is 22% - 30%. Assuming an 8% discount rate, the return on investment is 5:1 – 15:1[12].

In addition to economic benefits through lower consumer cost of electricity, NEMS reports significant environmental benefits. Overall US CO_2 and SO_2 emissions are reduced .5% to 1% and NOx emissions are reduced 3%-5%. Assuming constant generation, CO_2 emissions are

[9] Energy Information Admistration. Assumptions to AEO2011. http://www.eia.gov/forecasts/aeo/assumptions/index.cfm

[10] Geisbrecht, Rodney. Extending the CCS Retrofit Market by Refurbishing Coal Fired Power Plants.http://www.netl.doe.gov/energy-analyses/pubs/Refurbishment%20and%20Retrofitting%20in%20NEMS.pdf

[11] Since the NEMS is slightly more rigorous and bases its decisions on levelized cost of electricity vs. the internal rate of return/payback period method in the NPV model, this result is to be expected.

[12] Program funding levels of $13.6 million through 2025 (based on FY12 budget) and using NEMS model results of total US electricity bill savings through 2035 discounted at 8%.

reduced 20 million metric tons per year by 2035. This converts to a cost of CO_2 avoided of $2-$10/mt, which is a low cost option for reducing emissions.

6 Conclusions

The NPV and NEMS analyses of advanced sensors and controls shows that there is a market potential for 130GW to 300GW of the existing coal fleet to retrofit depending on capital cost and NSR requirements. Availability and efficiency are the key performance drivers in determining the economics of advanced sensor and control refurbishment projects. Reducing forced outages by 10% alone would make it economical for most of the coal fleet to refurbish at capital costs under $1 million. Assuming that at least half of the existing coal fleet can be economically retrofit with advanced sensors and controls by 2035, funding NETL research in this area provides a return on investment of 5:1 to 15:1. In addition to economic benefits through lower cost of electricity, coal fired power plant CO_2 emissions could be reduced around 1% or 20 million metric tons per year which converts to a cost of $2-$10/mt CO_2 avoided.